sustainability

MDPI

Article

The Utilization of Crop Residues as Forest Protection: Predicting the Production of Wheat and Rapeseed Residues

Petra Hýsková, Štěpán Hýsek * and Vilém Jarský

Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 6-Suchdol, 165 00 Praha, Czech Republic; gajdacova@fld.czu.cz (P.H.); jarsky@fld.czu.cz (V.J.)
* Correspondence: hyseks@fld.czu.cz

Received: 22 June 2020; Accepted: 17 July 2020; Published: 20 July 2020

check for updates

Abstract: Deforestation is a global threat in the form of the reduction of all of the ecosystem services provided to humans by forest ecosystems. For this reason, this article deals with the protection of forest ecosystem services by searching for a substitute for wood biomass. In recent years, the post-harvest residues of agricultural crops have been used mainly for energy and material uses. If this raw material is to be used industrially in the long term, we must have an idea of its future production. In most studies, predictions of future post-harvest residue productions are resolved in terms of the availability for energy sectors. This paper deals with the total amount of produced post-harvest residues that can be taken from the field; the post-harvest residue production for selected sectors is not subtracted from the overall prediction. Post-harvest residue production was estimated using the residue to product ratio (RPR), wherein the RPR coefficient was calculated for the monitored crops in each year, and the post-harvest residue production was subsequently calculated in each year according to the conversion rate characteristic for each year. The production of two widespread agricultural crops—wheat and rapeseed—was predicted. Linear regression models were used for the estimations. Based on these models, we predict the production of 58.3 million tonnes of post-harvest wheat residues and 22.4 million tonnes of post-harvest rapeseed residues in 2030 in the European Union. In the Czech Republic, we predict the production of 1.8 million tonnes of post-harvest wheat residues and 1.3 million tonnes of post-harvest rapeseed residues. The presented results can be used as the basis for further considerations of the material use of post-harvest residues and for the substitution of wood with these residues.

Keywords: crop residues; wheat; rapeseed; prediction; straw

1. Introduction

Deforestation is the most important factor causing the global loss of biodiversity, reducing the ability of soil to capture rainfall, and generally reducing all ecosystem services that forest ecosystems provide to humans [1]. Deforestation is prevented in most western countries. For example, the Czech Republic imposes an obligation on forest owners to reforest felled forests, and the clear-cut areas on forest plots must be afforested within two years and have forest stands established on them within seven years [2]. In Bavaria, for example, felled forests must be reforested within three years [3]. However, even in western countries where deforestation is very effectively restricted, the enforceability of these instruments is very limited. In the Czech Republic, for example, these obligations are met for the time being mainly due to the ownership structure of forests, where most of the forests are owned by the state or self-governing units. Of course, even state forest ownership or state control does not guarantee that deforestation will always be avoided, either legally or factually [4].

However, the situation in developing countries is even worse. Unsustainable logging activities in developing countries are mainly motivated by logging for material use, the logging of firewood and logging for charcoal production. The intensity of these unsustainable activities has a direct negative impact on the climate, the water cycle, soil erosion and biodiversity [5]. There are various strategies to prevent deforestation. Most countries try to solve this problem via government protection, e.g., by establishing large-scale protected areas [5,6]. Although there are various programs for the reclamation or reforestation of areas for harvested tropical rain forests, the ecosystem services provided by the restored ecosystems are lower than the original ecosystems. This is mainly due to lower biodiversity and poorer soil quality in the newly established stands on degraded soil [7]. Deforestation is most prevalent in tropical rain forests in developing countries, where post-harvest crop residues are also burned in the field [8,9]. Using the post-harvest biomasses of agricultural crops instead of mining biomass from tropical rainforests at the same location is therefore a logical option that is environmentally friendly. The material uses of post-harvest agricultural crop residues in developing countries can make a significant contribution to the protection of non-productive forest functions and carbon dioxide binding in materials for a longer period.

In recent years, post-harvest crop residues have had a wide variety of uses; in particular, the energy and material uses of this raw material are receiving scientific attention [10,11]. The material utilization of post-harvest residues is a very rational utilization, mainly due to carbon dioxide binding in products for a longer period of time [12,13]. Of course, those crops that are the most cultivated on a global scale are very interesting, as they produce a large amount of biomass which can be removed from the field after harvest and then utilized. Composite materials have already been produced successfully, for example from rice straw [14], rice husk [15], wheat straw [16], wheat husk [17], rapeseed straw [18], or the post-harvest residues of other crops [19].

The technology for producing composite materials from post-harvest agricultural crop residues is well mapped in the above-mentioned and many other studies. However, the future availability of lignocellulose raw material for the production of these composites is not as well described [20]. Several studies have already looked at the estimation of the future availability of post-harvest residues, particularly for energy use [21–23]. Given that the post-harvest residue production of agricultural crops is not systematically monitored, it is necessary to estimate this production.

Data concerning the expanses of the crop areas of agricultural crops and the production of individual crops are systematically monitored. This data is very well available in time series both at the national and transnational levels. However, the amount of post-harvest agricultural crop residues produced is not systematically monitored. This is because, until recently, post-harvest residues have not received much attention. They were used, for example, for ploughing and enriching the soil with the necessary organic substances, or as bedding for reared animals. As seed yield production is the main bearer of profit from crop agricultural production, these values are monitored. The worldwide increase in interest in post-harvest residues is very closely related to the increase in second-generation biofuels. The amount of post-harvest residues produced is judged on the basis of a calculation using the residue to product ratio (RPR) conversion rates, defined as the proportion of residues to agricultural production [24,25].

Many different models predicting crop production have been published, including models based on time series analysis, such as the linear regression model [26–28], the quadratic model [26,27], the Holt–Winter model [26] and the dynamic linear model [29]. If the future production of different crops is known, then the expected production of post-harvest residues can be easily calculated, as is presented, for example, in the studies of (BNEF) Bloomberg New Energy [30], Ericsson and Nilsson [21], and Searle and Malins [28]. However, the question is whether this procedure is appropriate. The weight fraction of the seeds and vegetative part of the plant depends on many factors, from climate, weather and soil conditions, through to the agronomic plan, and the variety of the crop. In addition, RPR declines with increasing hectare yield. However, the tightness of this dependence is not high, for the above reasons [25]. Furthermore, the inaccuracy of the conversion is due to the fact that farmers only maximize seed yield, which is influenced by the same factors as the seed weight ratio and post-harvest residues [31]. In addition to predicting the production of post-harvest residues using time series analysis, studies have been published that consider complex factors affecting future production and identify the main drivers of post-harvest residue production [32,33].

This present paper aims to estimate the future production of post-harvest wheat and rapeseed residues in the European Union and in the Czech Republic, using a different methodology for estimating post-harvest residue production than in the case of previously published research. These methodological differences are described in the paper, and the reasons are discussed. The proposed method was applied in this study to the prediction of the post-harvest residues of wheat and rapeseed in the European Union and in the Czech Republic. This methodology can also be applied to the prediction of these post-harvest residues in other regions if sufficient data are available.

2. Methods

Data on the production and crop areas of wheat and rapeseed from the Czech Statistical Office [34] and the Food and Agriculture Organization [35] were used for the prediction. When looking at post-harvest residues as a raw material for the production of composite materials, it makes sense to only consider dry matter. Absolute crop production values reported at normal moisture values were converted to zero humidity [36]. All the presented values on crop production and post-harvest residues are given in this text after conversion to zero humidity, i.e., only dry matter is used.

Given that the yield per hectare of crops varies from year to year, a solution was used in this work where the RPR was calculated for the monitored crops in each year, and subsequently the post-harvest residue production was calculated in each year according to coefficient characteristic for each year.

The RPR for the monitored crops was calculated according to the equations given in Scarlat et al. [25]:

The calculation for wheat:

$$RPR = -0.3629 \cdot \ln(x) + 1.6057 \quad (1)$$

The calculation for rapeseed:

$$RPR = -0.452 \cdot \ln(x) + 2.0475 \quad (2)$$

where x is hectare yield of the crop (t/ha).

The post-harvest residue production in individual years was then calculated as the product of RPR and the production of individual crops.

The data prepared in this way was used to predict post-harvest residue production. Future developments were assessed based on historical data. Therefore, the stable parameters affecting the given time series are assumed. A regression model was created using the Statistica12 program. Since the dependence of both wheat and rapeseed production on time has a linear nature in the monitored period, a linear regression model was used. Time series from 1993 to 2017 were used to predict post-harvest residue production in the European Union (EU-28), as both older and newer data are not available for the whole EU-28. As the development up to 2030 is predicted, longer time series were used to predict post-harvest residue production in the Czech Republic, from 1980 to 2018. Using the linear regression model created, it is possible to estimate the production of post-harvest residues. However, the amount of post-harvest residues available will certainly be lower, mainly because of sustainable agriculture, where a certain percentage of post-harvest biomass must be left in the field. The proportion of post-harvest residues that should be left in the field (the sustainable removal rate) depends on many factors, such as soil type, erosion, terrain slope, crop rotation and local conditions, etc. In their study, Searle and Malins [28] count the proportion of post-harvest residues left in the field as one third, irrespective of the crop. Similarly, de Wit and Faaij [37] expect a flat-rate of 50% of the post-harvest residues to be left in the field. Scarlat et al. [25] distinguish this percentage according to crops and, based on extensive research, state that only 40% of post-harvest wheat residues and 50% of rapeseed residues can be removed from the field in sustainable farming. The proposed coefficients in the Scarlat et al. [25] study were also used in the model in this work. A certain proportion of post-harvest residues are also consumed in the primary agricultural production itself, i.e., for the needs of livestock production.

It is therefore clear that not all of the predicted post-harvest residue production will be available for other processing sectors. In this study, however, unlike other authors [28,38], this part of the post-harvest residue is not subtracted from the overall prediction. We predict the total quantity of post-harvest residues produced that can be taken from the field under sustainable agricultural practices, regardless of the purpose. Of course, there are already currently consumers of post-harvest residues (livestock production, energy use, material use, mushroom cultivation, etc.), but there is no reason why we should subtract this consumption from total production. The consumption of post-harvest agricultural crop residues also changes over time, and therefore the subtraction of the post-harvest residue consumption in selected sectors by the coefficient alone only adds another inaccuracy to the model.

The goodness of fit to past data was evaluated by the root mean square error (RMSE) [29]:

$$RMSE = \sqrt{\frac{1}{M}\sum_{t=1}^{M}\left(Y_t - \hat{Y}_t\right)^2} \tag{3}$$

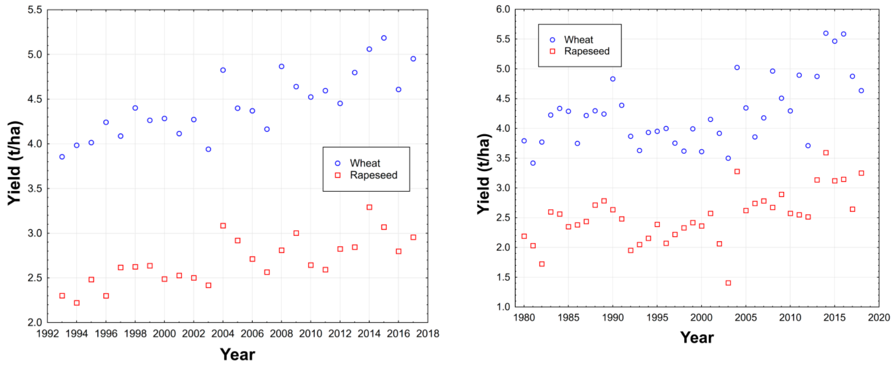
where Y_t is post-harvest residue production (tonnes), $\hat{Y}_t$ is the calculated post-harvest residue production based on the model used (tonnes) and M is number of observations (24 for European Union data, 38 for Czech Republic data).

In order to evaluate the predictive capabilities of the model, predictions of post-harvest residue production in the last known year (2017 for the EU and 2018 for the Czech Republic) were made using parameters calculated on the basis of a shortened time series of k. The value of k was set to 1 and 10 in order to evaluate the short-term and long-term prediction accuracy. The difference between the post-harvest residue production Y_t and the calculated post-harvest residue production based on shortened time series $\hat{Y}_t$ was expressed relative to the post-harvest residue production in the last known year:

$$\Delta_k = \frac{\left|Y_t - \hat{Y}_t\right|}{Y_t} \cdot 100\% \tag{4}$$

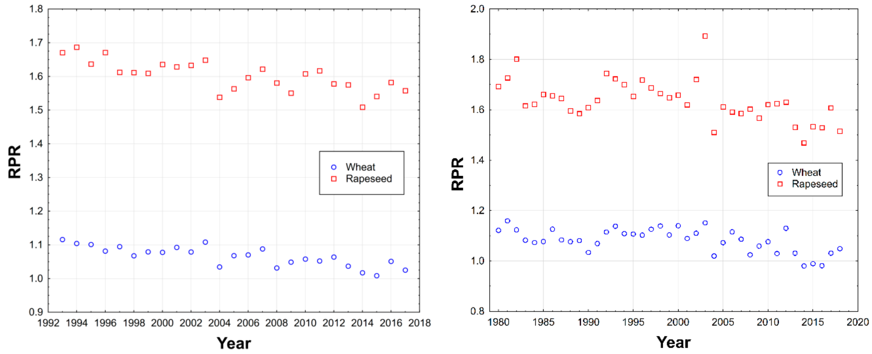
3. Results and Discussion

Figure 1 illustrates the variability of the wheat and rapeseed hectare yield in the monitored period in the European Union and the Czech Republic. This variability is, of course, also transferred to the calculated RPR coefficients, as shown in Figure 2. The RPR of wheat ranges from 0.98 to 1.22, and the RPR of rapeseed ranges from 1.47 to 1.92. The appropriateness of the calculation method, where the RPR that best describes a given year is used for each year, is therefore obvious. However, the use of a unique RPR for each year to estimate the post-harvest residue production is not common [21,28]. The decreasing trend of the RPR for both of the monitored crops fully corresponds to the predicted increasing hectare yield of wheat and rapeseed in the EU [31].



(**a**) (**b**)

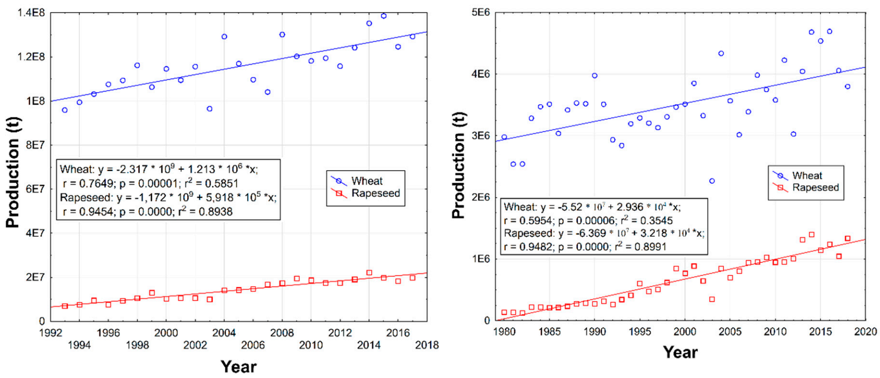
Figure 1. Hectare yield of wheat and rapeseed in the EU (**a**); hectare yield of wheat and rapeseed in the Czech Republic (**b**).



(**a**) (**b**)

Figure 2. Residue to product ratio (RPR) of wheat and rapeseed in the EU (**a**); residue to product ratio (RPR) of wheat and rapeseed in the Czech Republic (**b**).

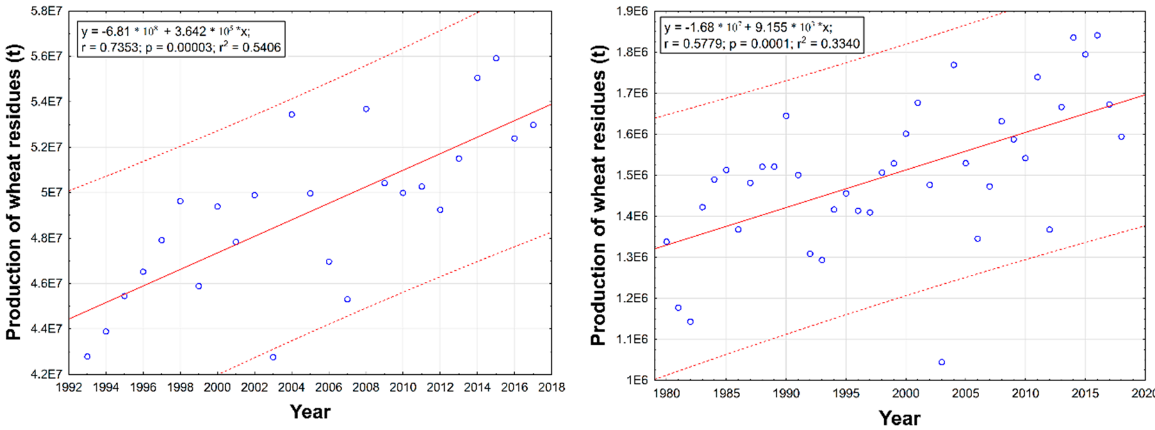
The production of both of the monitored crops has been increasing over the long term in the entire European Union and in the Czech Republic. In 2017, 129 million tonnes of wheat and 20 million tonnes of rapeseed [35] were produced in the EU. In the Czech Republic, 4.7 million tonnes of wheat and 1 million tonnes of rapeseed [39] were produced in 2017 (all of the data is recalculated to dry matter). Figure 3 depicts the linear nature of the dependence of the production of wheat and rapeseed on time over the monitoring period. The estimated parameters of all linear regression equations are statistically significant at the significance level of 0.05; therefore, the use of linear regression for the prediction of future production is justified. The estimated correlation coefficients show that the tightness of the relationship between rapeseed production and time is higher than that of wheat production.



(**a**) (**b**)

Figure 3. Development of wheat and rapeseed production in the European Union (**a**); the development of wheat and rapeseed production in the Czech Republic (**b**).

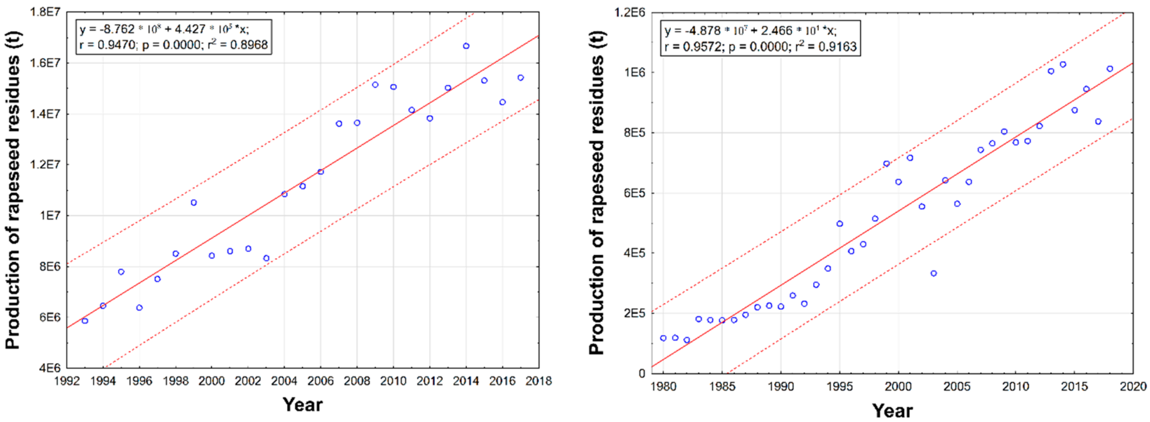
The estimated models of post-harvest wheat residue production (straw and husk) are shown graphically in Figure 4. The bars shown around the regression line represent the 95% confidence interval of the prediction in the displayed area. Post-harvest wheat residue production has long been increasing throughout the EU and in the Czech Republic.



(**a**) (**b**)

Figure 4. Model of post-harvest wheat residue production (specified in dry matter) in the European Union (**a**) and in the Czech Republic (**b**).

The estimated models of post-harvest rapeseed residue production are shown graphically in Figure 5. The bars shown around the regression line represent the 95% confidence interval of the prediction in the displayed area. The graph shows that the increase in post-harvest rapeseed residue production is steeper in both the EU and in the Czech Republic than the development of the post-harvest wheat residues.



(**a**) (**b**)

Figure 5. Model of the post-harvest rapeseed residue production (specified in dry matter) in the European Union (**a**) and in the Czech Republic (**b**).

Table 1 shows the predicted values of the total amount of post-harvest residues produced in 2030 that can be taken from the field under sustainable agricultural practices. In 2030, we predict the production of 58.3 million tonnes of post-harvest wheat residues and 22.4 million tonnes of post-harvest rapeseed residues in the European Union. The total amount of 80 million tonnes of post-harvest wheat and rapeseed residues corresponds, for example, to four times the annual consumption of wood in the European Union for the production of particleboards [19]. In the Czech Republic, we predict the production of 1.8 million tonnes of post-harvest wheat residues and 1.3 million tonnes of post-harvest rapeseed residues. In a previously published prediction, Searle and Malins [28] estimated that, by 2030, 109 million tonnes of post-harvest wheat residues will be produced in the EU that can be taken from the field. However, according to this study, only 54 million tonnes will be available on the market. These are significantly higher predicted values than in our model. For rapeseed, on the other hand, the figures in the Searle and Malins [28] predictions are lower than in our study, wherein they predict the total production for removal from fields at 15 million tonnes for 2030, and they estimate that a quantity of 7 million tonnes will be available on the market. The difference in these predicted values is due to a different methodology. Searle and Malins [28] used different RPRs for both of the observed crops (0.94 for wheat and 1.08 for rapeseed, with both coefficients being constant over time), subtracted post-harvest residue consumption from some sectors (one-third for both crops), recalculated the moisture differently, and also considered post-harvest residues—which need to be left in the field under sustainable agricultural practices (one-third for both crops)—with a different proportion for both crops.

Table 1. Estimation of post-harvest wheat and rapeseed residue production (dry matter) in the EU and in the Czech Republic in 2030.

	Linear Regression Model of Post-Harvest Wheat Production	**Estimate of Post-Harvest Wheat Production in 2030**	**Linear Regression Model of Post-Harvest Rapeseed Production**	**Estimate of Post-Harvest Rapeseed Production in 2030**
European Union	$y = -6.099 \times 10^8 + 3.6417 \times 10^5 \times x$	58.3 million tonnes	$y = -8.7624 \times 10^8 + 4.4268 \times 10^5 \times x$	22.4 million tonnes
Czech Republic	$y = -1.6798 \times 10^7 + 9.1554 \times 10^3 \times x$	1.8 million tonnes	$y = -4.8783 \times 10^7 + 2.4661 \times 10^4 \times x$	1.3 million tonnes

The characteristics of the goodness of fit and prediction accuracy of the models used are listed in Table 2. Although Michel and Makowski [29] reported the relatively poorer performance of using linear regression for wheat yield time series analysis, several authors [40–43] have already successfully used this regression for crop yield analysis. If a linear regression model is used, which assumes a constant increase in production, its limitations must be kept in mind. The use of a linear regression model for the prediction of future production presupposes a constant action of exogenous parameters. However, some phenomena, such as land use change or annual weather variations, are very difficult to predict [32]. The sustainable removal rate is also an important factor for sustainable agriculture. It is not excluded that future agronomic practices will adjust this rate [44], but in this study, it is considered constant over time. On the other hand, the methodology used in this study removes the limitation emphasized by Wietschel et al. [32]. Wietschel et al. [32] considered a constant RPR in their study, while in the present article a unique RPR for each year is used, and its development is estimated on the basis of past values.

Table 2. Goodness of fit and prediction accuracy.

	RMSE (Tonnes)		**Δ_1(%)**		**Δ_{10}(%)**	
	Wheat	**Rapeseed**	**Wheat**	**Rapeseed**	**Wheat**	**Rapeseed**
European Union	2,474,848	1,191,631	1.2	9.2	2.9	0.9
Czech Republic	147,680	87,271	5.8	3.3	0.1	6.5

The motive of most of the research estimating post-harvest residue production is to quantify this production to determine the availability of biomass for energy purposes [21,37,45,46]. However, estimates from these studies are not comparable to the results we predict because they are not sufficiently generalized and focus only on biomass production for energy purposes. A certain part of the research then aims to quantify the production of post-harvest biomass in the past period, without predicting the future [25,33,47]. The highly detailed, multi-factor models published in the study by García-Condado et al. [33] and Scarlat et al. [48] estimate the production of post-harvest residues in the

EU in the past. It would be useful to apply these models to the predicted data and use this methodology to estimate production for the future.

4. Conclusions

If post-harvest crop residues are to be used industrially in the long term, it is necessary to know their future production. The study published in this article deals with post-harvest wheat and rapeseed residues, where the future production of this biomass was estimated using a linear regression model. Several characteristic elements were used in the created models that distinguish them from the predictions of other authors. In particular, the residue to product ratio coefficient was calculated separately each year for the monitored crops, and subsequently the post-harvest residue production was calculated in each year according to the conversion rate characteristic for each year. Furthermore, the estimates deal with the total amount of post-harvest residues produced, which can be taken from the field within the framework of sustainable agriculture. We do not subtract any part of the post-harvest residue production for the selected sectors from the overall prediction. The output of this study is an estimate of the production of wheat and rapeseed post-harvest residues in the EU and the Czech Republic in 2030; these data can be used as input data in further decision making and planning concepts for the material use of post-harvest residues. The results show that, in 2030, 58.3 million tonnes of post-harvest wheat residues and 22.4 million tonnes of post-harvest rapeseed residues can be harvested from the field in the European Union. In the Czech Republic, 1.8 million tonnes of post-harvest wheat residues and 1.3 million tonnes of rapeseed residues can be harvested from the field. If we consider post-harvest crop residues as a substitute for wood biomass, the increase in the material use of post-harvest residues can reduce deforestation worldwide and thus prevent the degradation of forest ecosystem services.

Author Contributions: Conceptualization, P.H.; Data curation, P.H.; Investigation, P.H.; Methodology, P.H. and Š.H.; Supervision, V.J.; Validation, Š.H.; Writing—original draft, P.H. and Š.H.; Writing—review and editing, V.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by 'Advanced research supporting the forestry and wood-processing sector's adaptation to global change and the 4th industrial revolution', OP RDE (Grant No. CZ.02.1.01/0.0/0.0/16_019/0000803) and the APC was funded by the Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences.

Acknowledgments: The authors are grateful for the support of 'Advanced research supporting the forestry and wood-processing sector's adaptation to global change and the 4th industrial revolution', OP RDE (Grant No. CZ.02.1.01/0.0/0.0/16_019/0000803).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Fugère, V.; Nyboer, E.A.; Bleecker, J.C.; Chapman, L.J. Impacts of forest loss on inland waters: Identifying critical research zones based on deforestation rates, aquatic ecosystem services, and past research effort. *Biol. Conserv.* **2016**, *201*, 277–283. [CrossRef]
2. Forestry Act, no. 289/1995 Coll. Zákon o lesích a o změně některých zákonů (lesní zákon) [Act on Forests and Amendments to some Acts (the Forest Act)]. Available online: https://www.zakonyprolidi.cz/cs/1995-289 (accessed on 23 March 2020).
3. Art. 15 Bavarian forest Act. (GVBl S. 313) BayRS 7902-1-L Art. 15 Bayerisches Waldgesetz (BayWaldG) in der Fassung der Bekanntmachung vom 22. Juli 2005 (GVBl. S. 313, BayRS 7902-1-L), das Zuletzt Durch § 3 Abs. 2 des Gesetzes vom 27. April 2020 (GVBl. S. 236) geändert worden ist. Available online: https://www.gesetze-bayern.de/Content/Document/BayWaldG-15 (accessed on 23 March 2020).
4. Le Tourneau, F.-M. Is Brazil now in control of deforestation in the Amazon? *Cybergeo* **2016**, *10*, 769. [CrossRef]
5. Eguiguren, P.; Fischer, R.; Günter, S. Degradation of Ecosystem Services and Deforestation in Landscapes With and Without Incentive-Based Forest Conservation in the Ecuadorian Amazon. *Forests* **2019**, *10*, 442. [CrossRef]

6. Tan-Soo, J.-S.; Adnan, N.; Ahmad, I.; Pattanayak, S.K.; Vincent, J.R. Econometric Evidence on Forest Ecosystem Services: Deforestation and Flooding in Malaysia. *Environ. Resour. Econ.* **2016**, *63*, 25–44. [CrossRef]
7. Chazdon, R.L. Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Lands. *Science* **2008**, *320*, 1458–1460. [CrossRef]
8. Srinivasarao, C.; Lal, R.; Kundu, S.; Babu, M.B.B.P.; Venkateswarlu, B.; Singh, A.K. Soil carbon sequestration in rainfed production systems in the semiarid tropics of India. *Sci. Total Environ.* **2014**, *487*, 587–603. [CrossRef]
9. Ziegler, A.D.; Phelps, J.; Yuen, J.Q.; Webb, E.L.; Lawrence, D.; Fox, J.M.; Bruun, T.B.; Leisz, S.J.; Ryan, C.M.; Dressler, W.; et al. Carbon outcomes of major land-cover transitions in SE Asia: Great uncertainties and REDD+ policy implications. *Global Change Biol.* **2012**, *18*, 3087–3099. [CrossRef]
10. Jiang, D.; Zhuang, D.; Fu, J.; Huang, Y.; Wen, K. Bioenergy potential from crop residues in China: Availability and distribution. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1377–1382. [CrossRef]
11. Kalia, S.; Dufresne, A.; Cherian, B.M.; Kaith, B.S.; Avérous, L.; Njuguna, J.; Nassiopoulos, E. Cellulose-Based Bio- and Nanocomposites: A Review. *Int. J. Polym. Sci.* **2011**, *2011*, 1–35. [CrossRef]
12. Hýsek, Š.; Podlena, M.; Böhm, M.; Bartsch, H.; Wenderdel, C. Effect of Cold Plasma Surface Pre-treatment of Wheat Straw Particles on Straw Board Properties. *BioResources* **2018**, *13*, 5065–5079. [CrossRef]
13. Ramamoorthy, S.K.; Skrifvars, M.; Persson, A. A Review of Natural Fibers Used in Biocomposites: Plant, Animal and Regenerated Cellulose Fibers. *Polym. Rev.* **2015**, *55*, 107–162. [CrossRef]
14. Xia, T.; Huang, H.; Wu, G.; Sun, E.; Jin, X.; Tang, W. The characteristic changes of rice straw fibers in anaerobic digestion and its effect on rice straw-reinforced composites. *Ind. Crops Prod.* **2018**, *121*, 73–79. [CrossRef]
15. Muthuraj, R.; Lacoste, C.; Lacroix, P.; Bergeret, A. Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation. *Ind. Crops Prod.* **2019**, *135*, 238–245. [CrossRef]
16. Sitz, E.D.; Bajwa, D.S. The mechanical properties of soybean straw and wheat straw blended medium density fiberboards made with methylene diphenyl diisocyanate binder. *Ind. Crops Prod.* **2015**, *75*, 200–205. [CrossRef]
17. Hýsek, Š.; Podlena, M.; Bartsch, H.; Wenderdel, C.; Böhm, M. Effect of wheat husk surface pre-treatment on the properties of husk-based composite materials. *Ind. Crops Prod.* **2018**, *125*, 105–113. [CrossRef]
18. Hýsková, P.; Hýsek, Š.; Schönfelder, O.; Šedivka, P.; Lexa, M.; Jarský, V. Utilization of agricultural rests: Straw-based composite panels made from enzymatic modified wheat and rapeseed straw. *Ind. Crops Prod.* **2020**, *144*, 112067. [CrossRef]
19. Klímek, P.; Wimmer, R. *Alternative Raw Materials for Bio-Based Composites*; Bioresources: Brasov, Romania, 2017.
20. Gajdačová, P.; Hýsek, Š.; Jarský, V. Utilisation of Winter Rapeseed in Wood-based Materials as a Solution of Wood Shortage and Forest Protection. *BioResources* **2018**, *13*, 2546–2561. [CrossRef]
21. Ericsson, K.; Nilsson, L.J. Assessment of the potential biomass supply in Europe using a resource-focused approach. *Biomass Bioenergy* **2006**, *30*, 1–15. [CrossRef]
22. Graham, R.L.; Nelson, R.; Sheehan, J.; Perlack, R.D.; Wright, L.L. Current and Potential U.S. Corn Stover Supplies. *Agron. J.* **2007**, *99*, 1–11. [CrossRef]
23. Kluts, I.; Wicke, B.; Leemans, R.; Faaij, A. Sustainability constraints in determining European bioenergy potential: A review of existing studies and steps forward. *Renew. Sustain. Energy Rev.* **2017**, *69*, 719–734. [CrossRef]
24. Bentsen, N.S.; Felby, C.; Thorsen, B.J. Agricultural residue production and potentials for energy and materials services. *Prog. Energy Combust. Sci.* **2014**, *40*, 59–73. [CrossRef]
25. Scarlat, N.; Martinov, M.; Dallemand, J.-F. Assessment of the availability of agricultural crop residues in the European Union: Potential and limitations for bioenergy use. *Waste Manag.* **2010**, *30*, 1889–1897. [CrossRef]
26. Boken, V.K. Forecasting Spring Wheat Yield Using Time Series Analysis: A Case Study for the Canadian Prairies. *Agron. J.* **2000**, *92*, 1047–1053. [CrossRef]
27. Kumar, V.; Haque, C.E. Forecasting wheat yield in the Canadian Prairies using climatic and satellite data. *Prairie Perspect.* **1998**, *1*, 81–92.
28. Searle, S.; Malins, C. *Availability of Cellulosic Residues and Wastes in the EU 2013*; The International Council On Clean Transportation: San Francisco, CA, USA, 2013.
29. Michel, L.; Makowski, D. Comparison of Statistical Models for Analyzing Wheat Yield Time Series. *PLoS ONE* **2013**, *8*, e78615. [CrossRef]

30. (BNEF) Bloomberg New Energy Moving Towards A Next-Generation EthanolEconomy: Final Study 2012. Available online: https://about.bnef.com/blog/moving-towards-a-next-generation-ethanol-economy-report/ (accessed on 23 March 2020).
31. EC EU agricultural outlook for markets and income, 2018–2030. Available online: https://ec.europa.eu/info/news/eu-agricultural-outlook-2018-2030-changing-consumer-choices-shaping-agricultural-markets-2018-dec-06_en (accessed on 23 March 2020).
32. Wietschel, L.; Thorenz, A.; Tuma, A. Spatially explicit forecast of feedstock potentials for second generation bioconversion industry from the EU agricultural sector until the year 2030. *J. Clean. Prod.* **2019**, *209*, 1533–1544. [CrossRef]
33. García-Condado, S.; López-Lozano, R.; Panarello, L.; Cerrani, I.; Nisini, L.; Zucchini, A.; Van der Velde, M.; Baruth, B. Assessing lignocellulosic biomass production from crop residues in the European Union: Modelling, analysis of the current scenario and drivers of interannual variability. *GCB Bioenergy* **2019**, *11*, 809–831. [CrossRef]
34. CSO Zemědělství—Časové Řady [Agriculture—Time Series]. Available online: https://www.czso.cz/csu/czso/zem_cr (accessed on 23 March 2020).
35. FAOSTAT Crops—Data. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 23 March 2020).
36. EUROSTAT. *Annual Crop Statistics Handbook 2019*; Edition 2019; EUROSTAT: Luxembourg, 2019.
37. de Wit, M.; Faaij, A. European biomass resource potential and costs. *Biomass Bioenergy* **2010**, *34*, 188–202. [CrossRef]
38. Bakker, R.R.C.; Elbersen, H.W.; Poppens, R.P.; Lesschen, J.P. *Rice Straw and Wheat Straw—Potential Feedstocks for the Biobased Economy*; NL Agency: Utrecht, The Netherland, 2013.
39. CSO Statistická Ročenka České Republiky—2018 [Statistical Yearbook of the Czech Republic 2018]. Available online: https://www.czso.cz/csu/czso/statistical-yearbook-of-the-czech-republic-2018 (accessed on 23 March 2020).
40. Hafner, S. Trends in maize, rice, and wheat yields for 188 nations over the past 40 years: A prevalence of linear growth. *Agric. Ecosyst. Environ.* **2003**, *97*, 275–283. [CrossRef]
41. Finger, R. Evidence of slowing yield growth–The example of Swiss cereal yields. *Food Policy* **2010**, *35*, 175–182. [CrossRef]
42. Lin, M.; Huybers, P. Reckoning wheat yield trends. *Environ. Res. Lett.* **2012**, *7*, 024016. [CrossRef]
43. Rondanini, D.P.; Gomez, N.V.; Agosti, M.B.; Miralles, D.J. Global trends of rapeseed grain yield stability and rapeseed-to-wheat yield ratio in the last four decades. *Eur. J. Agron.* **2012**, *37*, 56–65. [CrossRef]
44. VDLUFA. *Humus Balancing: A Method for the Analysis and Assessment of the Humus Provision of Cultivated Farmland (in German)*; VDLUFA: Speyer, Germany, 2014.
45. Monforti, F.; Bódis, K.; Scarlat, N.; Dallemand, J.-F. The possible contribution of agricultural crop residues to renewable energy targets in Europe: A spatially explicit study. *Renew. Sustain. Energy Rev.* **2013**, *19*, 666–677. [CrossRef]
46. van Dam, J.; Faaij, A.P.C.; Lewandowski, I.; Fischer, G. Biomass production potentials in Central and Eastern Europe under different scenarios. *Biomass Bioenergy* **2007**, *31*, 345–366. [CrossRef]
47. Kim, S.; Dale, B.E. Global potential bioethanol production from wasted crops and crop residues. *Biomass Bioenergy* **2004**, *26*, 361–375. [CrossRef]
48. Scarlat, N.; Fahl, F.; Lugato, E.; Monforti-Ferrario, F.; Dallemand, J.F. Integrated and spatially explicit assessment of sustainable crop residues potential in Europe. *Biomass Bioenergy* **2019**, *122*, 257–269. [CrossRef]